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LIFE CYCLE MANAGEMENT • CASE STUDY

Environmental implications and market analysis of soft drink packaging systems in Mexico. A waste management approach

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Abstract

Background, aim, and scope This paper presents a waste management analysis of the packaging systems for soft drinks in Mexico, with emphasis on polyethylene terephthalate (PET) containers. The work presented is part of a project sponsored by a consortium of Mexican industries that participate in the PET market, such as resin producers, bottle manufacturers, soft drinks producers, distributors, and plastic recyclers. Two different life cycle assessments (LCAs) were elaborated to provide insight on waste management scenarios and waste products comparisons, respectively. The first LCA was a description of the actual PET market and PET waste treatment in Mexico. On the second LCA, three systems were analyzed: PET bottles, aluminum cans, and glass bottles. Currently, these results are used in Mexico as a basis for environmental policy.

Materials and methods PET bottle's participation in the market has increased substantially in the previous years, and it is forecasted that this increase rate will continue. Due to this factor, there are some concerns about the environmental implications of PET usage. In order to analyze the waste management of PET bottles in Mexico, an LCA and a series of sensitivity analyses were conducted in order to understand: (1) the effect of different collecting distances in environmental impacts, (2) the effect of different recycling rates in environmental impacts, (3) the effect of different collecting rates in environmental impacts, and (4) the effect of different collecting rates with its associated distances in the environmental impacts.

Results and conclusions An optimal degree of PET waste collection was identified as a result of considering different collecting rates and distances. At this point, minimum environmental impact occurs. This is due to the excessive increase in environmental resources that is needed in order to collect higher amounts of waste by traveling longer distances. These results may pose significant implications on current environmental legislation and waste management policies in Mexico and can well be applied into other Latin-American and developing countries. Other results show that production processes represent the highest environmental impacts along the supply chain, which are considerably higher than those impacts related to transport and collecting activities. Because of this, the environmental advantages of waste management in Mexico can be significant as long as the material that is collected is also recycled. Results to be presented include specific impact data on electricity generation and transport in Mexico.

Recommendations and perspectives This work can be used as a basis for decision making in environmental policy. Moreover, it provides technical grounds to demonstrate that under certain conditions, traditional waste management systems may cause higher environmental impacts than the environmental benefit/credit that they are supposed to deliver.

Keywords Life cycle assessment · Mexico · Polyethylene terephthalate (PET) · Soft drink packaging systems · Waste management

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1 Background, aim, and scope

The Mexican market of bottled water and soft drinks has experienced a significant growth; more than 6,000 million gallons of drinks are sold every year. Some decades ago, glass was used for bottling these products; nowadays, polyethylene terephthalate (PET) is the most common material used for this purpose. The main advantages of this material are its price, low weight, easiness to be blown into almost any mold, ability to prevent loss of carbonation and flavor, among others.

Even though PET is a recyclable material, industries and governments are concerned about its related environmental impacts. The main issues are associated with landfill space availability and pollution generated from PET production. Currently, there are no analytical tools to describe the environmental implications of changes in the PET market structure or in its different waste management policies.

The aim of this project is to provide a joint analysis of the future situation of the PET market and its environmental impact. In order to achieve these goals, a simulation model and a life cycle assessment (LCA) have been carried out (Angell and Klassen 1999). The first tool has been used for market demand forecasting (including several possible future scenarios) and the second for evaluating the environmental effect of PET soft drink containers. The framework presented in this work has been developed for the Mexican context but can be easily adapted to any other market.

2 PET plastic market model

2.1 Model description

PET goes through several stages during its life cycle, as presented in Fig. 1. PET resin can either be imported or produced in Mexico. There are different types of resin, which are designed for three main segments: bottling, textile production, and film fabrication. Bottling is mainly carried out by carbonates, bottled water, and oil producers. Once the beverage is consumed, most of the bottles are disposed into landfills, while some are collected by recyclers. Collected PET follows two mainstreams: It may be recycled or exported as raw material. The recycled material is then reintroduced to the production system after following one of three different processes: chemical, mechanical, or thermal recycling.

Market distribution has not been constant in the previous years. Therefore, part of this work aimed to understand the behavior of each market segment in order to develop a model that could be used to forecast PET demand, using historical information (APME 2002; Arena et al. 2003; APREPET 2004 and personal communications). In addition, the model considered not only market growth but also the increase of PET usage in each particular industry (Azapagic et al. 2004).

2.2 Simulation model

The main advantage of using simulation (as opposed to a regression analysis) is that PET market behavior can be recreated for studying. It allows companies to predict, under a probabilistic risk assessment scheme, which scenarios are more likely to occur within the next years (Kelton et al. 2002). Based on the information provided by the simulation, the companies may develop their strategies to be more competitive (Romero-Hernandez et al. 2005).

The simulation model used data from several PET sub markets. Three types of statistics were collected regarding each market: first, the historical demand of PET for each of these markets; second, the growth rate of every market during the last years and the forecasted growth rates for

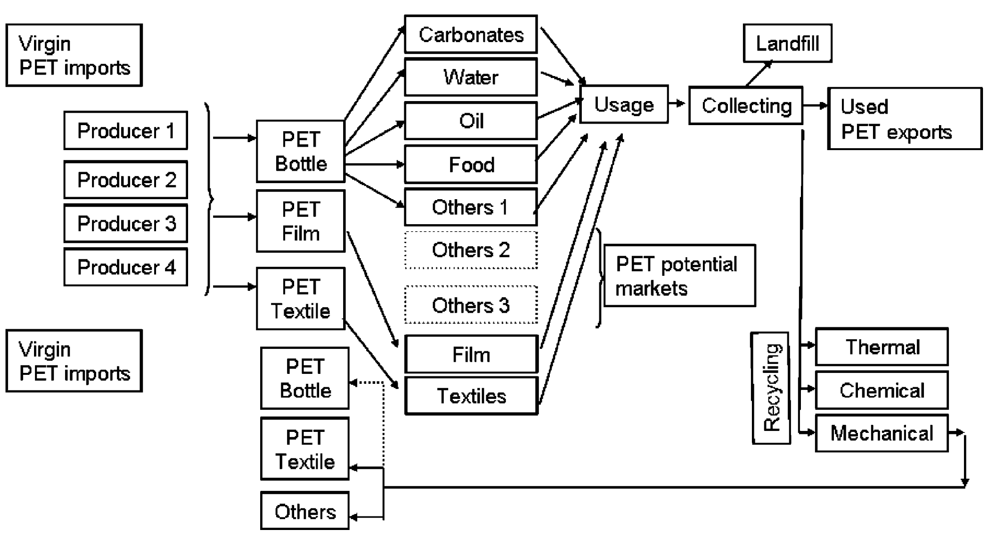

Fig. 1 Schematic approach of PET market in Mexico

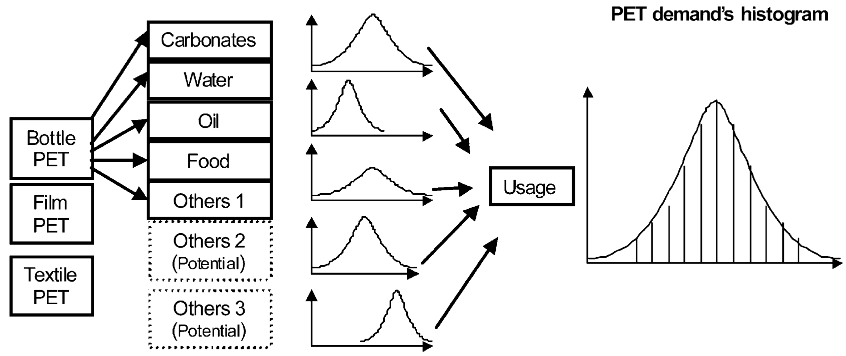

Fig. 2 Schematic overview of the PET demand forecasting model

future years; and finally, the growth of PET's share within each market.

The aforementioned data was used to generate probability distributions for the growth rate of the demand of PET for each submarket. The probability distribution of each sector was adjusted into a statistical beta function. Once the beta distributions were derived, they were incorporated into a scheme similar to the one showed in Fig. 2 in order to provide the outcome of PET demand for each year. In other words, demand for each market was first calculated by simulation, and these demands were then aggregated in order to generate the probability distribution for the PET market demand in Mexico for the next years.

The previous model was applied to generate various scenarios for PET demand in the following 5 years. Figure 3 shows the results obtained from the simulation for the first year (2003) and the period 2003–2007, respectively.

3 Environmental process performance

The model shown in Fig. 1 also represented the basis for evaluating the environmental impact produced along the life cycle of PET bottles (from raw materials extraction to final disposal). LCA was used to evaluate the environmental performance of these bottles along their supply chain (Azapagic et al. 2004; Romo et al. 2005).

3.1 Forecast for PET recycling quantity and rate

The results of the abovementioned simulation model, combined with the information gathered from visits and interviews to collecting and recycling companies and landfill managers and employees, allowed one to forecast the quantity of PET bottles that would be collected and recycled the following years. Figures 4 and 5 show that even though the total quantity of PET collected would increase every year, the recycling rate would decline. The reason for this was that market demand for PET would grow faster than collecting infrastructure.

3.2 Life cycle assessment

LCA is used to determine environmental impacts of processes (Romero 1998; Romero-Hernandez 2004; Romero-Hernandez 2005) or products (Norris 2003). The complex interaction between a product and the environment along its life cycle can be studied with this tool. It may be used to determine the amount of energy required in each process and quantify the pollutants emitted at each step of the supply chain, from the extraction of virgin materials to

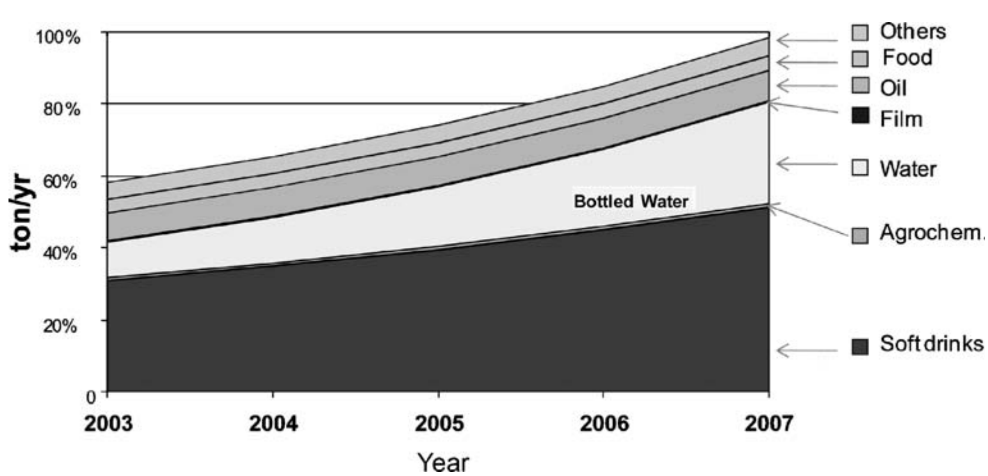

Fig. 3 Forecast of PET plastic market in Mexico (2003–2007)

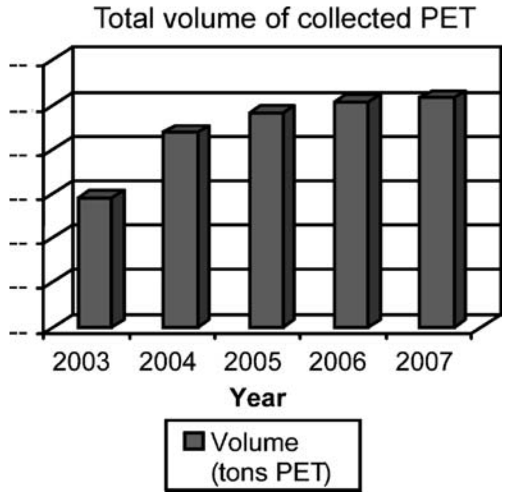

Fig. 4 Forecast of PET collected in Mexico (2003–2007)

the final disposal of the product (Doka and Hischier 2005; Roy and Vezina 2001; Ward and Duray 2000).

Since the elaboration of an LCA requires the consideration of specific characteristics of the system that is being studied, Mexican conditions had to be incorporated in the inventory analysis. Therefore, information about emissions for electricity generation and transportation in Mexico had to be integrated in this project.

3.2.1 Inventory of emissions for electricity generation in Mexico

Table 1 presents the final results of an inventory of emissions developed for Mexican electricity generation. This inventory was obtained from the literature from the Energy State Department and the Environment and Natural Resources State Department, interviews with government employees, and emissions reported by energy plants. Results are in the same order of magnitude as those found in SimaPro and GaBi for other countries (IKP 2005). There are 177 electricity plants in Mexico (2002). As such, the data used in our study represents almost 17% of total production sites.

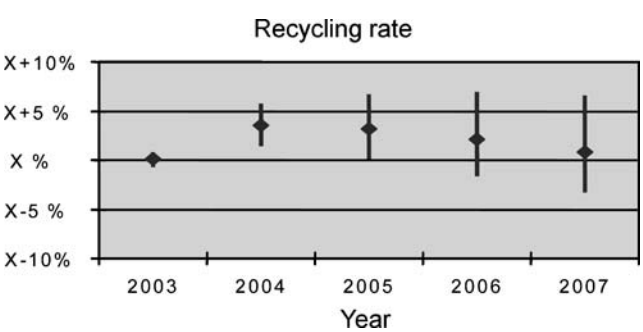

Fig. 5 Forecast of PET plastic market in Mexico (2003–2007)

Table 1 Results of an inventory of emissions developed for Mexican electricity generation

Emissions/gross generation (ton/GWh)	Ton/GWh	kg/MJ
SO_2	10.9	0.00302778
NO_x	1.95	0.00054167
TSP (total suspended particles)	0.7	0.00019444
VOC	0.021	5.8333E−06
CH_4	0.016	4.4444E−06
N_2O	0.0082	2.2778E−06
CO	0.21	5.8333E−05
Total	13.8052	0.00383478
CO_2 (GEI)	688	0.19111111

3.2.2 Inventory of emissions for transport in Mexico

The inventory of emissions was based on the LCA framework and open literature (Spielmann and Scholz 2005). Emissions related to road transport were obtained by analyzing more than 2,700 real data emissions generated by the vehicle verification program in Mexico. These records represent a small fraction of the total number of vehicles in the metropolitan area (approximately 4 million). However, we believe that 2,700 observations represent a valid sample and a fair reference on the behavior of vehicles in Mexico. The results are shown in Table 2. (g bhp^{-1} h^{-1}). Emissions are stated as grams per brake horsepower per hour. This is a measurement of exhaust emissions due to engine power output.

3.3 Environmental impact assessment

The environmental impact along the PET bottles life cycle was measured basically in terms of several category indicators. However, due to space limitations, we are only illustrating results related to global warming potential (GWP). As seen on Fig. 6, this life cycle presents two main stages: the production of *bottled beverage* and the *waste scenario phase*. In this figure, the line thickness is set to express the contribution of each process to the whole

Table 2 Results of observations on behavior of vehicles

LPG vehicles	g bhp^{-1} h^{-1}
NO_x	0.81
CO_2	166
CO	1.1
Soot	0.01
N_2O	0.06
VOC	0.35
Non methane VOC	0.34
Methane	0.01

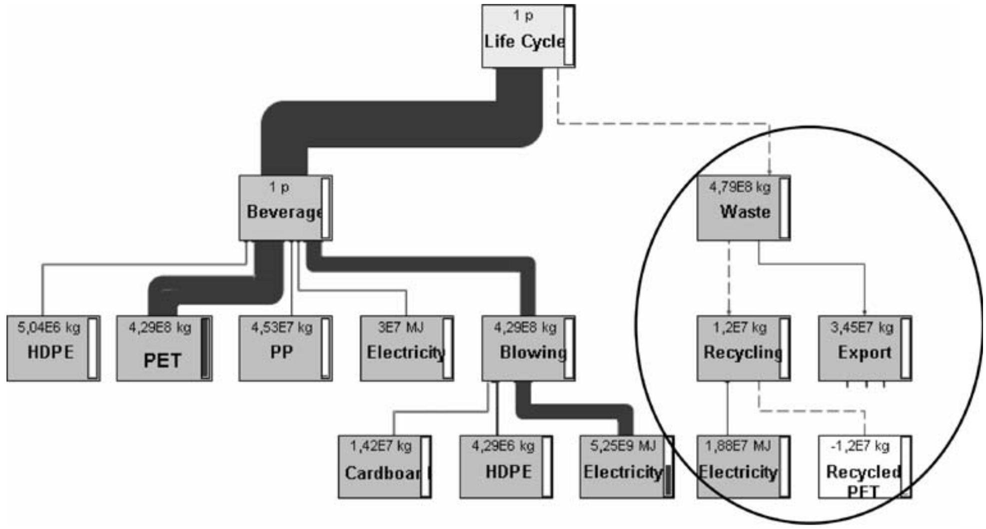

Fig. 6 Environmental impact (global warming) of various stages in the supply chain

environmental impact. Solid lines indicate an adverse effect, while dotted lines represent a positive impact.

The main source of negative GWP impact (measured in terms of CO_2 equivalent emissions) of the PET bottles life cycle is the PET production process. The second most significant contributor to GWP is the blowing process. This is due to the amount of electricity required to blow each preform with hot air until it is converted into a bottle.

In contrast, the waste scenario presents a positive effect to the environment. Higher recycling rates of PET represent lower amounts of virgin PET. As recycled PET is used for other applications such as textile and building materials, there is no need to produce virgin PET. As a consequence, those activities related to the production of beverage containers are avoided, reducing GWP in the system considered in this LCA.

Waste scenario considered the insight provided by the International Expert Group on LCA for Integrated Waste Management (Thomas and McDougall 2004) and other authors (Ménard et al. 2004; Martchek 2006). The Waste Scenario process (shown in Fig. 7) has an overall favorable GWP impact since there is a favorable GWP effect related to PET recycling. This thick dotted line indicates that recycling brings a beneficial effect to the total amount of equivalent CO_2 emitted in Mexico as a consequence of PET production. However, the waste scenario also presents a negative impact related to the transport and processing of disposed PET bottles, which include collecting from urban and rural centers, shredding, packaging, and final delivery. These results suggest that there might be a point at which marginal benefits related to recycling will be lower than the negative impacts of processing and transport.

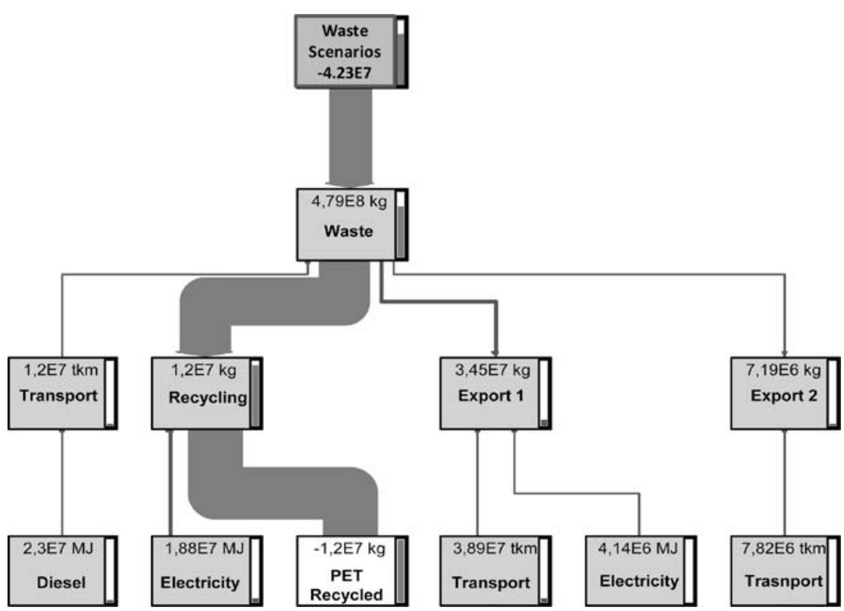

Fig. 7 Environmental impact (global warming) of the waste scenario

4 Sensitivity analysis

A series of sensitivity analyses were conducted in order to understand: (1) the effect of different collecting distances in environmental impacts, (2) the effect of different recycling rates in environmental impacts, (3) the effect of different collecting rates in environmental impacts, and (4) the effect of different collecting rates with its associated distances in the environmental impacts. Due to space limitations in this paper, we present the combined effect of these variables. Although nine environmental indicators were evaluated, this article presents results related to GWP. The other results are available upon request.

Two hypothetical scenarios were developed as part of the sensitivity analysis. These scenarios were based on interviews with major PET collectors in Mexico. As such, two transport scenarios that related the relative average distance traveled in each collecting trip with the amount of PET that could be collected were studied.

In scenario a, it is assumed that larger distances (than those presented in scenario b) are required for higher collecting percentages. In scenario b, an average distance of 400 km is required to collect 60% of all PET bottles disposed, whereas in scenario a, more than 600 km are required to achieve a 40% collecting percentage. These scenarios are not linear. It is important to note that major PET collectors identified 60% as the highest recycling rate that can be achieved by means of traveling longer distances. The remaining 40% is a consequence of the lack of enough automated sorting processes. Most of the PET bottles are sorted manually at the landfill; hence, a great amount of bottles end up buried.

Results presented in Fig. 8 show that, as the recycling rate increases from 0% to approximately 35%, the environmental impact (measured in terms of GWP) decreases. However, after this point, the total GWP impact increases constantly as the recycling rate augments. In terms of environmental policy, this means that after 35%, collecting PET represents higher costs and higher environmental impacts. Therefore, at this rate, the environmental impact is minimized.

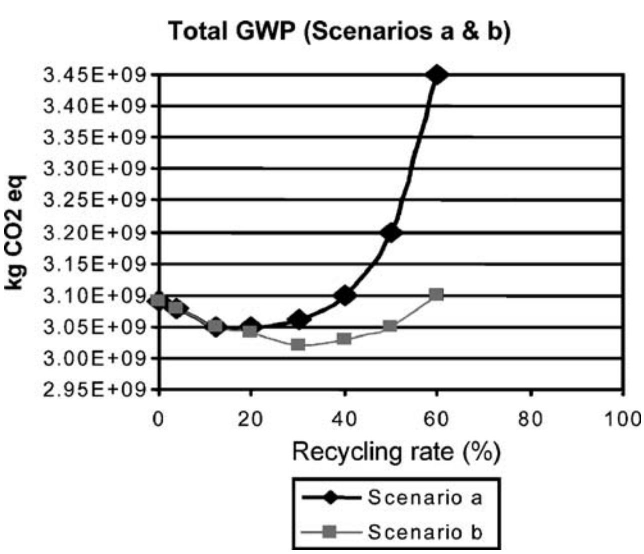

Fig. 8 Effect of recycling rate on global warming potential (GWP)

5 Conclusions

This work presents a general framework for analyzing the market and environmental effects along the supply chain and life cycle of one of the most successfully introduced plastic materials in the soft drink packaging systems: PET.

Simulation models developed in this work for various processes and operations related to PET confirmed to be a significant source for understanding the main effects of market variations into the quantity of product demanded and, consequently, production levels. Specifically, this model allowed for an understanding of the impact of each submarket (soft drinks, bottled water, food, etc.) into the overall demand.

PET consumption will continue its increasing shape for the following years. Soft drinks will remain as the major submarket for PET bottles. However, simulation results show that water is the submarket that will grow at the highest pace. Results on PET demand contrast with those on the waste scenario. Although the total PET volume collected will increase constantly, the recycling rates (kg collected/kg produced) will eventually decrease. This is due to the fact that the PET production rate will be higher than the PET collecting rate.

2Environmental performance was also an issue of concern. In this respect, the model was robust enough to describe the interactions and environmental effects related to each process in the supply chain: raw material extraction, raw material transformation, plastic production, bottles manufacturing, beverage production, transport, use, disposal, collection, recycling, and landfiling. One of the main advantages of the analysis framework presented in this paper is that it supports the understanding of complex systems. Moreover, once characterized, the system can be continuously modified in order to understand the effect of various variables into the whole economic or environmental impact.

LCA proved to be a valuable tool for understanding the relative environmental impacts along the supply chain. However, a considerable limitation of this tool was the lack of specific information related to electricity generation and transport in Mexico. This limitation was overcome with two projects: (1) gathering and sorting real data from at least 30 major electricity plants,

literature research, interviews with government department employees, and technical experts in electricity generation and (2) gathering, sorting, and analyzing information from at least 2,700 vehicle emissions. Major results of both projects were presented in this paper, and it is the authors' desire to make them public and promote further research in this field.

LCA results demonstrated that the major GWP contributor along the supply chain is the production of the PET resin, followed by preform transformation into the final shape of the bottle. These results highlighted the importance of analyzing the alternative of reducing PET resin production. As such, this paper presented the effect of various waste scenarios, where recycling rates were studied as a function of collecting distance.

In the range of 0% to 35%, it was found that higher recycling rates lead to lower relative environmental impacts (measured in terms of GWP). However, after this point, the total GWP impact increases constantly as the recycling rate augments due to environmental loads associated with transport, sorting, and packaging. In terms of environmental policy, this means that after 35%, collecting PET represents higher costs and environmental impacts. Therefore, it can be said that the environmental impact is minimized at this rate.

All results presented in this paper are partial and case-specific. The research project included the evaluation of eight other environmental impact indicators and more sensitivity analysis. Due to space limitations and confidentiality agreements, these results are not presented in this paper but can be available upon request.

The insight behind this research can be easily adapted into almost any process or material. As such, this work can be a basis for comparing different design alternatives and in identifying competitive advantages in the selection of products, processes, and materials.

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